

Tevatron constraints on the Higgs boson mass in the fourth-generation fermion models revisited

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Abstract

Recent Tevatron exclusion interval of the masses of Higgs boson considerably reduces in case of the light quasistable fourth generation neutral lepton.

If the fourth sequential quark-lepton generation does exist then the cross section of Higgs boson production at hadron colliders is considerably enhanced in comparison with that in Standard Model (SM) [1]. This result was used in a recent Tevatron paper according to which a standard-model-like Higgs boson in the mass interval

$$131 \text{ GeV} < m_H < 204 \text{ GeV} \quad (1)$$

is excluded at the 95% Confidence Level in the model with the fourth generation [2]. The statement about exclusion follows from Fig. 4c of [2], where an experimental upper bound on the product $\sigma(gg \rightarrow H) \times \text{Br}(H \rightarrow W^+W^-)$ is compared with the theoretical prediction for this product.

The result obtained in [2] strongly depends on the lower mass bounds on the fourth generation fermions. The point is that the new decay channel $H \rightarrow f\bar{f}$ opens if a mass of any of these new particles is less than $m_H/2$. Then $\text{Br}(H \rightarrow W^+W^-)$ diminishes and the exclusion interval of m_H reduces. Concerning the fourth generation quarks we know from Tevatron that their

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masses are larger than 300 GeV [3]. The mass of the charged lepton m_E is bounded to be above 100 GeV by LEP II, so the decay $H \rightarrow E^+ E^-$ practically does not occur for m_H from the excluded domain. For the fourth generation neutrino a lower bound on its mass $m_N > 80$ GeV obtained at LEP II [4] is used in [2]. In [2] two scenarios are considered: $m_N = 80$ GeV (low mass scenario) and $m_N \gg 80$ GeV (high mass scenario). The above mentioned exclusion interval of m_H refers to low mass scenario; for high mass scenario an exclusion interval of m_H stretches till $m_H = 208$ GeV.

The aim of the present note is to stress that a lower bound $m_N > 80$ GeV [4] is applicable only to the case when the mixing angle of the fourth generation neutral lepton with at least one neutral lepton from three light generations is larger than $3 \cdot 10^{-6}$. In this case N decays to charged leptons from the first three generations inside L3 detector. For smaller mixing angles (quasistable N) the mass of N is bounded only from the analysis of Z boson decays, $m_N > 46.7$ GeV [5].¹ If the decay of Higgs boson to a pair of heavy neutral leptons is kinematically allowed, then it dominates [6]. In [7] we study how Standard Model Higgs boson branching ratios is changing in the presence of light N .

In Fig. 1 we compare the branching ratios of Higgs to WW calculated with modified HDECAY code [8] for $m_N = 80$ GeV, $m_E = 100$ GeV, $m_U = 450$ GeV, $m_D = 400$ GeV (black curve) with the branchings used in [2] (red curve). The agreement between two calculations is very good. In Fig. 2 the same branching ratios for $m_N = 46.7$ GeV are shown.

In the Table we present the branching ratios of $H \rightarrow W^+ W^-$ decays for $m_N = 80$ GeV and for $m_N = 46.7$ GeV for m_H from 110 to 300 GeV.

¹Since N is at least 10^{11} times heavier than the heaviest of three SM neutrinos, a values of the lepton mixing angles $\theta_{i4} \approx \sqrt{m_{\nu i}/m_N} < 3 \cdot 10^{-6}$ look quite natural.

Table

m_H (GeV)	Br ($H \rightarrow W^+W^-$) $m_N = 80$ GeV	Br ($H \rightarrow W^+W^-$) $m_N = 46.7$ GeV
110	0.03	0.005
120	0.08	0.01
130	0.19	0.02
140	0.35	0.04
150	0.55	0.10
160	0.85	0.37
170	0.88	0.68
180	0.83	0.73
190	0.69	0.67
200	0.65	0.65
210	0.62	0.63
220	0.60	0.62
230	0.59	0.61
240	0.58	0.61
250	0.58	0.60
260	0.58	0.60
270	0.57	0.60
280	0.58	0.60
290	0.58	0.60
300	0.58	0.60

Branching ratios of $H \rightarrow W^+W^-$ decays for two values of m_N .

From the Table we see, that branching ratio of the decay $H \rightarrow W^+W^-$ considerably diminishes for $m_H < 160$ GeV. Taking this effect into account from Figures 4(c-d) and Tables I-II of [2] we obtain the following model independent exclusion interval:

$$155 \text{ GeV} < m_H < 204 \text{ GeV} \text{ excluded at 95\% C.L.} \quad . \quad (2)$$

Our second comment refers to the case of $m_N > 80$ GeV. Fourth generation change considerably the constrains on m_H from electroweak precision data. In particular, one can choose the values of the fourth generation masses

so, that heavy Higgs is allowed. Only an upper bound $m_H \lesssim 1$ TeV from perturbative unitarity [9] remains.

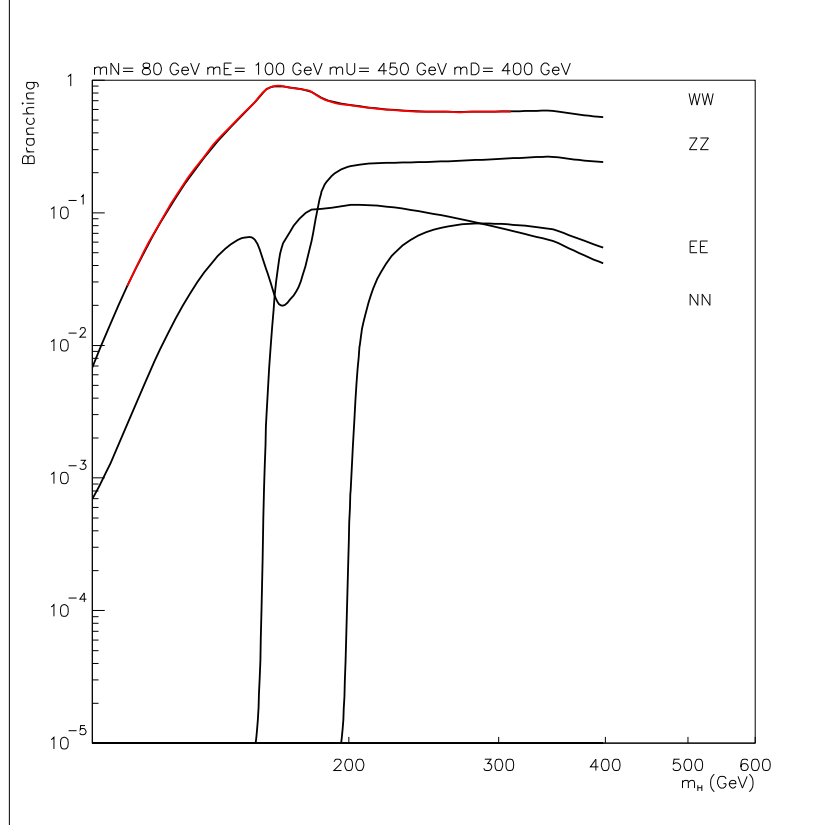


Fig. 1. *Branching ratios of Higgs boson decays in case of fourth generation with $m_N = 80$ GeV. Red line corresponds to the branching ratios from the last column of Table I of the CDF-D0 paper [2]. (The values $m_E = 100$ GeV, $m_U = 450$ GeV, $m_D = 400$ GeV are used).*

In [10] we study the value of m_H (where minimum of χ^2 of the electroweak data fit occurs) as a function of the mass of the neutral lepton N . According to Fig. 5 from [10] for the case of one extra generation and the fourth lepton heavier than 80 GeV, Higgs boson mass less than 240 GeV corresponds to the χ^2 minimum. It would mean that a considerable part of the allowed interval of m_H is depreciated by the bound (1) valid for $m_N > 80$ GeV. However, in the analysis of paper [10] we neglect a possible CKM type mixing of the fourth generation quarks with the quarks of three “light” generations. This

mixing was taken into account in the recent paper [11] with the following result: for $m_N = 101$ GeV and sine of quark mixing angle $s_{34} \sim 0.1 \div 0.2$ the value of m_H up to 600 GeV is allowed.

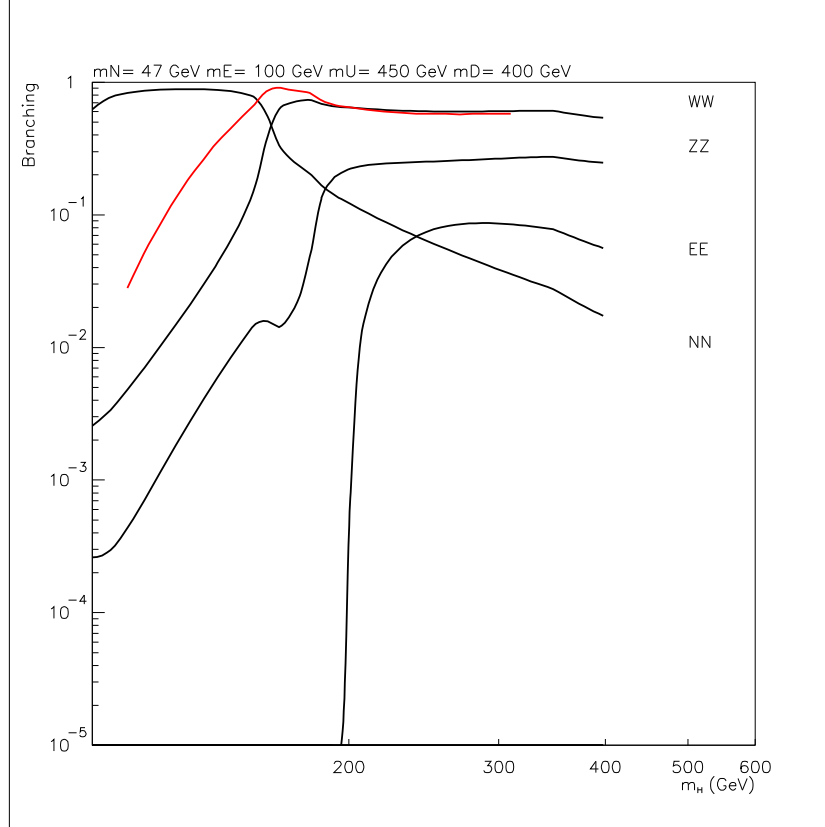


Fig. 2. *Branching ratios of Higgs boson decays in case of fourth generation with $m_N = 46.7$ GeV. Red line demonstrates growth of the branching ratio of Higgs decay into WW for $m_N = 80$ GeV. (The values $m_E = 100$ GeV, $m_U = 450$ GeV, $m_D = 400$ GeV are used).*

At the absence of mixing in accordance with our results [10] Tevatron bound (1) almost excludes the existence of the fourth generation with heavy N . However the conclusion of [11] that zero CKM mixing s_{34} is excluded is not valid for the interval of heavy neutrino masses $m_N = 46.7 - 70.0$ GeV.

In a very interesting recent paper [12] the fourth generation with extremely small mixing with lighter three generations is considered. The main issue of [12] is the preservation of baryon and lepton asymmetries against

sphaleron erasure in this model. The fact that the exclusion interval of the higgs boson masses (1) diminishes to (2) in case of the quasistable N enlarge the allowed parameter space which could be used in [12]. The bounds from the EW precision data are discussed for the case of light N in the STU formalism in [12]. In [10] we specially address an issue of inapplicability of STU formalism in the case of light N . The use of the proper parameters (V_i or S', T', U') would change the allowed domain in the $m_U - m_D$ plot (Fig 1) of [12].

In summary, we demonstrated that model independent exclusion interval of the values of Higgs boson masses from Tevatron direct searches in case of fourth generation is reduced to $155 \text{ GeV} < m_H < 204 \text{ GeV}$, by allowing small heavy neutrino masses $m_N = 45.7 - 80.0 \text{ GeV}$.

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